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A Study of Alloys with Reference
to their Acid-Resisting Properties

Chemical Engineering

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A STUDY OF ALLOYS WITH REFERENCE TO THEIR
ACID-RESISTING PROPERTIES

BY

BANESVAR DASS

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CHEMICAL ENGINEERING

COLLEGE OF LIBERAL ARTS AND SCIENCES

UNIVERSITY OF ILLINOIS

1914

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Banesvar Dass

ENTITLED A Study of Alloys with Reference to their Acid-
resisting Properties.

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE
DEGREE OF Bachelor of Science in Chemical Engineering

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291738



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INTRODUCTION

History and Classification

The use of the metals gold, silver, mercury, copper, iron, tin and lead, particularly of iron, was known to the ancients. ¹The iron tools found in the great Egyptian pyramids, the iron pillar of Delhi, India, and the mention of gold, silver, copper, etc., in the old literary works are more than enough to justify the above statement.

²The tendencies of metals to unite with each other under certain conditions to form alloys has long been known and probably usefully applied from remote antiquity. A large variety of alloys of copper with tin and other metals was known to the ancients. They used these alloys for many purposes for which they are used by the moderns. Culinary pots were made of the alloy of copper and tin and the arms of the ancients were often made of bronze. Tin was in common use in the time of Moses and it has also been mentioned by Homer. Tin was used in these days for the coating of copper and brass vessels. The ancient Romans used mercury for alloying with gold and silver to form amalgams. The early Egyptians, the Arabians and the Romans used large quantities of lead which they obtained from Spain and Great Britain for lead piping and other similar purposes. A mixture of lead and tin was also used as a solder.

Iron has been known and used from early times. Probably men first obtained iron from the meteoric stones in small quantities before manufacturing it from its ores in large quantities by the direct process. The iron works of Delhi and Egyptian pyramids existing to-day, deriding thousands of earthquakes, equinoctial hurricanes, equatorial heat and the tropical rains, not only show that our ancestors knew the use of iron, but also bear witness to the wonderful skill they attained in its manufacture. Everything in nature is subject to decay and the metals are no exception to this general rule. It is due to this cause that we have not enough old metallic specimens left from which we can say how flourishing the iron industry was in the early ages. But from the fact that comparatively few metallic tools have been discovered, which undoubtedly date back to the remote period in the history of civilization, it does not follow that the metallic industry was not in a flourishing condition. Whether or not the causes of corrosion of metals were known to them, their materials seem to have been made in such a way as to resist corrosion. The iron pillar of Delhi, built in 900 B. C. has been corroded but a very little, although openly exposed to the atmospheric and other corrosive influences. It is this corrosion that has led to the development of the so-called non-corrosive alloys which we find in the market to-day. Corrosion of metals and alloys is something with which the chemists and chemical engineers have to contend in their every day industrial works. The

pure metals are usually more non-corrosive than the impure ones, but unfortunately in nature we never find absolutely pure metals which could be used for industrial purposes. This necessitates the use of impure metals and alloys and subjects us to troubles arising from corrosion. Many attempts have been and are being made to make alloys of non-corrosive properties.

A systematic and scientific investigation of the nature of alloys began in the eighteenth century. The French chemist Reaumur, was the first man to discover the presence of sulphur in steel. At the end of that century, Berthelot showed experimentally that steel contains a compound of iron and carbon. In the early part of this century, Musschenbroek performed experiments on the tensile strength of metals and alloys. The investigations of many other eminent chemists of this period brought many new facts which excited a good deal of interest of the educated public in this particular field of investigation. The researches on alloys became more and more numerous in the early part of the nineteenth century and has continued to grow to the present day.

^{3,4}There are many theories that have been advanced by different investigators at different times about the ^{se} corrosion of the materials of construction. But of these the acid theory and the electrolytic theory are the most important and most generally accepted. Other theories have been proposed, but proved inadequate. The acid theory was advanced by Crace Calvert and is based upon the assumption that pure liquid and oxygen are not sufficient of themselves

to effect the corrosion, but that at least a trace of carbonic acid or some other acid must be present.

The electrolytic theory was proposed by Whitney in 1903. According to this theory the presence of acid is not necessary to effect corrosion, but that corrosion will take place even in weak alkaline solutions. According to Whitney the process of rusting is nothing but an electro-chemical phenomenon, being simply a function of electromotive force and circuit resistance. The water, acting as an electrolyte, is ionised into hydrogen and hydroxyl ions, and of these the hydrogen ions cause the metals to pass into solution.⁵

⁶The metals and alloys can be classified into two main groups, namely the corrosive and the non-corrosive metals and alloys. All of these materials in use are subject to corrosion to a certain extent. Hence this division on the basis of corrosion depends upon the fact that some metals and alloys are comparatively more corrosive than the other metal metals and alloys. The precious metals as gold, platinum, etc., are very resistant to corrosion and while they are very durable and strong, they are not used for industrial purposes on a large scale on account of their high cost. Aluminium, zinc, lead, etc., on the other hand do resist corrosion very satisfactorily and so they are used for especial purposes in the industrial world. Some metals, though themselves unable to resist the action of acids, attain a very high power of resistance towards corrosion when alloyed with some other metals. Thus we have a large number of alloys on

the market at the present time which are used for industrial purposes, both because of their acid-resisting properties and the lower cost of production.

Non-corrosive metals and alloys are coming more and more into use and are thus gradually replacing the corrosive ones on account of the short durability of the latter. But still there are some metals and alloys which, though corrosive, are indispensably used in the industrial works on account of some other good qualities in them, such as the high tensile strength, ultimate strength, conductivity, etc. For example, iron which is easily corroded has the largest use in industry for its above-mentioned desirable and workable properties.

The ability to resist corrosion has a great influence in the value of the material. If the metals be arranged in order of their power to resist corrosion, it will be found that those metals that can offer greater resistance to corrosion are more valuable than those that are less resistant to corrosion. For example, platinum, gold and silver are more costly than nickel, tin, aluminum, copper, zinc, lead and iron taken in order. But it must be understood that the value of these metals is dependent upon many other economic factors, such as scarcity in nature, etc., besides corrosion. Also high tensile strength, etc., play an important part in the use and value of the metals. There are many acid-resisting materials that are practically of no use at all simply for the lack of these properties (tensile strength, etc.).

Acid-resisting materials having workable properties are

extensively used in all the industrial works of the present day. But their principal uses are in the sulphuric acid, coke and refrigerating plants. Aluminum is extensively used where nitrates, sulphates and many organic acids are manufactured. Lead is almost universally used in sulphuric acid and coke plants where ammonium sulphate is manufactured. Refrigerating plants mostly use galvanized iron. Thus different metals are used in different plants to meet the particular needs under these conditions.

⁷There are several artificial ways of protecting metals and alloys from corrosion. This kind of protection is greatly needed in order to increase their life and thus make them more valuable and more useful.

The principal method of protecting materials of construction from corrosion is by means of protective coatings of which the following might be mentioned.

- (1) By paints, varnishes, lacquer, etc.
- (2) By galvanizing or sherardizing.
- (3) By electroplating.
- (4) By the use of adherent coating of magnetic oxide of iron.

In the first process, the materials are completely covered by paints, varnishes, etc., in such a way that the metallic parts may not be exposed to the corrosive action of air, water and other corroding agencies. In the second process, they are covered with some other metal (zinc for example) in the form of an adherent coating by some mechanical means and thus subjecting the coatings to the corrosive influences, rather than the metals themselves. In electro-

plating, the metallic surface is covered by electro-deposition with an adherent coating of some other metal⁸. The second metal is deposited for decorative purposes or for superior resistance to chemical and atmospheric influences.

⁹The last process is known as the gun metal finish. In this process, the black oxide of iron, Fe_3O_4 , is produced on the finished articles. This oxide when put on and properly treated, protects the articles from corrosion.

Metals are also alloyed to considerably increase their power to withstand the action of the acids. This process will be described in detail later on.

Properties and Manufacture

In order to be good for industrial works, all alloys must have some desirable qualities. In general the property of resisting the action of acids, alkalies, etc., is the most important of all the properties desired in the alloys, for there is hardly any industry at the present day where the corroding agents, acids, alkalies, etc., etc., are not used in some way. Alloys of which the different parts of the plants are made, thus invariably come in contact with the corroding agents. Hence in order to avoid considerable expense in frequent replacing of the different parts of the plant, the above property in the alloys is especially desirable. The tensile strength of the alloys comes next in importance. No matter how acid-resisting the alloys may be, if poor in tensile strength, they can not be used for machines or subjected to heavy stresses which are in-

dispensably necessary for industrial works. The property of hardness is also very desirable for some particular purposes. It also has a very good effect in giving the alloy, high tensile strength. Some alloys, however, are almost useless because of being too hard and hence too brittle. Another thing that deserves due consideration in the alloy, is the simplicity of its manufacture and the low cost of its production. The alloy may possess all the desirable properties, but the process of its manufacture may be so complicated and the cost of its production may be so high as to offset the advantages of the superiority of its properties and thus make its commercial success impossible. Regardless of these requirements the alloy must be workable, for no matter how good an alloy is so far as its properties and simplicity of manufacture are concerned, it is almost useless if it be not workable. Besides these properties, high density, bright color, ductility, malleability, thermal and electrical conductivities are usually very important properties in the alloys.¹⁰

All metals are capable of forming alloys with some other metal or metals, more or less easily. While a good deal of work has been done on the constitution of alloys, the investigators up to this time have determined the constitution of only some of the simple alloys. As to the constitution of the more complex alloys, practically nothing has been done. The constitution of the binary alloys is supposed to be one of the following two forms¹¹. (a) The

two substances entering into the series do not form chemical compounds. (b) The two substances form one or more chemical compounds.

Under these two general types of alloys there are several classifications which will not be discussed here.

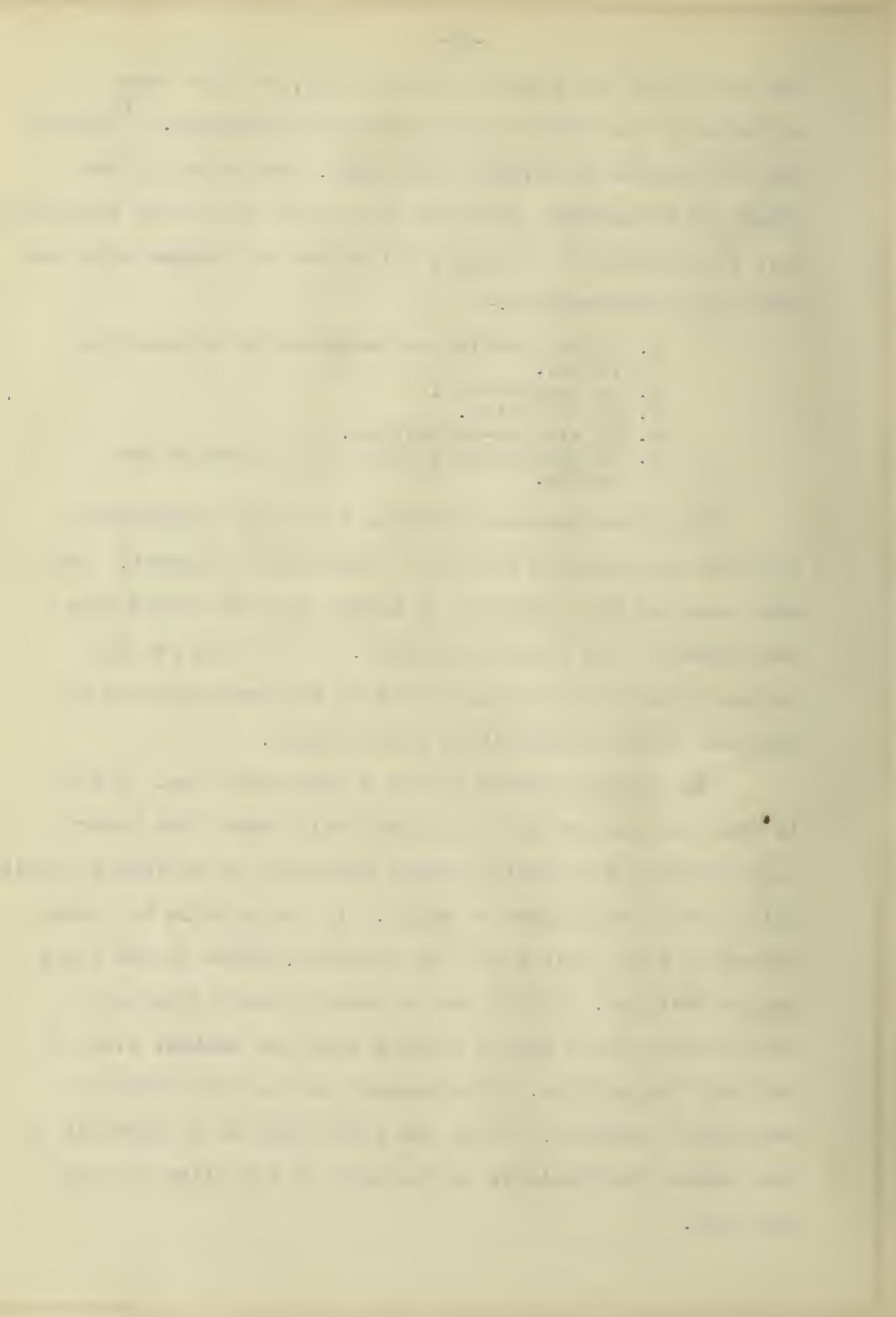
¹²The common and obvious practice of making alloys consists in mixing the different metals which are to be alloyed in the desired proportions and then melting them into alloy, usually in a crucible. Electric and ordinary type furnaces are also used for this purpose. It is a common belief in trade that any alloy is improved by remelting, and so this is practiced in many cases, particularly in the brass foundries. The quality of an alloy is largely dependent upon the proportions of the components used and the proper treatment, either in mixing or melting. An alloy of good composition may turn out to be useless for want of proper heat treatments, whereas an alloy of poor composition may yield a product of superior properties with the proper treatments. Alloying in atomic proportions is advocated by some chemists, but the products obtained in this way do not always answer the demands for which they are intended. Hence this proportion is seldom used in practice. In fact, there is hardly any definite rule about the proportions and treatments of the metals to make up an alloy. It is simply a matter of trial and alloys are made in their

own particular and definite proportions, to make them suitable to the needs for which they are intended. ¹³ Alloys may be prepared in several other ways, some of which are purely of theoretical interest and others being used commercially. The methods of preparing alloys may be grouped into the following five headings:-

1. By sublimation or condensation of metallic vapors.
2. By compression.
3. By diffusion.
4. By electro-deposition.
5. By simultaneous reduction of two or more metals.

The first process of making alloys by condensation of metallic vapors is purely of theoretical interest. But some cases of the formation of alloys by this method have been found in the furnace products. It is also possible to make alloys of iron and nickel by the decomposition of mixtures of the carbonyls of these metals.

The second process is not a commercial one. But it is possible and has been experimentally shown that under high pressure the finely divided particles of different metals unite into a solid mass or alloy. If the mixture be forced through a small hole with high pressure, wires of the alloy may be obtained. Alloys can be made by the diffusion of solid metals which are in contact with one another even at ordinary temperature. This process is also very rare in commercial practice, but it has been shown to be possible in many cases, particularly in the case of the alloy of lead and gold.



The fourth process of making alloys by electro-deposition is a commercial success, but it is practicable only to a limited number of alloys, because of the many difficulties. By passing an electric current, under suitable conditions, through a solution containing the salts of different metals to be alloyed, the metals are deposited in the form of a true alloy. But this process works best when the salts of only two metals are used in the solution.

The fifth process of making alloys by simultaneous reduction of metals is more and more receiving the attention of the chemists and coming into commercial use. This process known as the Goldschmidt or thermit process depends upon the powerful affinity of aluminium for oxygen whereby it combined with the oxygen of the metallic oxide leaving the free metal. For example:-



For making alloys the oxides of the different metals to be alloyed are mixed in the desired proportions, the theoretical quantity of granulated aluminium added to the mixture, and then the reaction begun with the help of some accelerator. In this reaction enough heat is evolved to cause the metals to melt and unite in the form of a true alloy. The accelerator consists of powdered aluminium and an easily reducible oxide such as sodium peroxide. The accelerator is placed on the top of the mixture of metallic oxides in the crucible, and by igniting a magnesium wire which is inserted into the mixture, the reaction is started.

Many alloys, namely ferro-manganese, ferro-chrome, ferro-silicon, etc., are manufactured by the simultaneous reduction of the two metals in the blast or the electric furnaces. This process was tried in making some alloys in this work which will be discussed later.

EXPERIMENTAL PART

Method

¹⁴ There are several ways of testing metals and alloys with reference to corrosion. The following are the principal methods in actual practice:-

1. Sea-water tests.
2. Acid tests.
3. Alkali tests.
4. Atmospheric tests.

The greatest number of experiments appear to have been made in connection with the corrosion of metals and alloys by sea water. Many investigators have made these tests on the materials which are used for shipbuilding and thus come in contact with sea water. In this test, the samples to be tested are first weighed, suspended in the sea water for a certain length of time, weighed again and the loss in weight due to the action of sea water calculated.

In order to determine the corrodibility of metals and alloys in acids and alkalies, the samples are suspended in the same way in the acids and alkalies of known concentration by some convenient means for a certain length of time at a certain temperature. The difference in weights of the samples before and after the acid treatment is the loss due to the action of corroding agents. This method of testing

alloys is very important and very commonly used.

In the atmospheric tests, the samples are exposed to the action of atmosphere for a certain length of time and its effect determined from the change in color or lustre of the samples or by weighing as in the above cases.

If all the conditions of time, temperature, concentration, etc., are carefully observed, these different tests give a very good general idea of the relative power of the metals and alloys to resist corrosion and from these results something can be told about their fitness for industrial purposes.¹⁵ In this work the acid resisting properties of the different metals and alloys have been investigated. In this kind of an investigation, some importance must be attached to the method of exposing all the different parts of the samples to the action of the acids. They can not be hung by means of wires, unless the wires are made of gold or platinum and this is out of the question because of the expense. To avoid the difficulty of having the suspending wire dissolve, the following means was devised. Thin pieces of glass rods were bent into convenient form to hold the samples to be tested and then suspended on the side of the beaker containing the acid. This method gives the advantage of exposing all the different parts of the samples to the action of acids without contaminating them. Besides, in this way, the samples are held firmly and do not fall to the bottom of the beaker during the test. The acids used in this work were hydrochloric, nitric and sulphuric of 4 N

concentration. The samples tested were all obtained from the different companies in this country and they were cut into such pieces in a machine as to give a surface area that can be easily and accurately measured. After the pieces were accurately weighed and measured for the surface area, the different samples were held in the above mentioned way in the 4 N. hydrochloric, nitric and sulphuric acids for twenty-four hours at room temperature. At the end of this time, the pieces were taken out, washed thoroughly first with water and then with alcohol, dried completely, and weighed. The difference in these two weights is the loss due to the action of acids on the samples. This loss was then calculated in grams per square inch of the surface exposed to the action of the acids. Thus the results obtained give direct comparison of the loss in weight of the different materials due to the action of 4 N acids in 24 hours at room temperature.

¹⁵ Some of the investigators in similar work have expressed their results on the basis of the percentage loss of the samples after treatment with the acids. However, there seems to be some disadvantage in making the calculations in this way, since the loss of samples in acids is directly dependent upon the surface of the samples in contact with the acids, other conditions, namely, the strength of acids, length of time of exposure and temperature being kept constant. Hence two samples of the same metal or alloy of equal weight, but of different surface area, being treated in acids of same strength for the same length of time at

the same temperature, will show different percentage losses, although there will be hardly any appreciable difference in losses per square inch of the surface. Hence it was thought more desirable to make the calculations in loss per square inch of surface area.

In tabulating the results of these tests, the samples have been arranged in order of their relative power to resist the action of sulphuric acid, beginning with the one that stands the action of sulphuric acid the most. Sulphuric acid has been taken as the standard for the comparison of the acid resisting properties of the different metals and alloys, for the reason that it is this acid with which we come in contact a great deal more than any other acid.

SOLUBILITY OF ALLOYS AND METALS.

			Loss in weight in grams per sq. in. of surface in 4 N			
No.	Names of alloys	Composition	HCl	HNO ₃	H ₂ SO ₄	Remarks
1	Copper Lead Tin and Zinc alloy	Cu = 76 % Pb = 14 % Sn = 8 % Zn = 2 %	0.1840	96.00	0.0382	
2	Copper Lead Tin and Zinc alloy	Cu = 85 % Pb = 7 % Sn = 1 % Zn = 7 %	0.1120	44.60	0.0512	
3	Copper Lead Tin and Zinc alloy	Cu = 82 % Pb = 2 % Sn = 12 % Zn = 4 %	0.1340	8.760	0.0568	
4	Cadmium		0.5240	Entire	0.5800	Misplaced
5	Copper and aluminium alloy		0.3690	18.3600	2.370	Misplaced
6	Parson's man- ganese bronze		0.200	Entire	0.0905	
7	Chrome- copper	Cr = 10 % Cu = 90 %	2. 26	Entire	0.109	
8	Monel metal	Ni = 68.72 % Fe = .515 % S = .140 % C = .073 % Cu = balance	0.1930	20.90	.1147	
9	Copper bear- ing steel	C = .210 % Mn = .510 % P = .024 % S = .039 % Cu = .480 % Fe = 98.75 %	0.920	39.4000	2.1000	Misplaced
10	Escher wyss metal	Cu = 56-62 % Zn = 43.3 - 35 % Si = 0.20 - 1.5 % Sn = 0.50 - 1.5 %	0.244	Entire	0.157	

No.	Names of alloys	Composition	Loss in weight in grams per sq. in. of surface in 4 N			Remarks
			HCl	HNO ₃	H ₂ SO ₄	
11	Ferro-molybdenum	Mo = 80 % Fe = 20 %	0.286	Entire	0.198	
12	Aluminium		1.06	0.40	0.2200	
13	Nichrome	Ni = 90 % Cr = 10 %	3.66	4.54	0.4525	
14	Nickel		2.20	15.90	1.08	
15	Silver-aluminium alloy		14.75	4.20	1.18	Rich in Ag. not homogeneous
16	Copper, Nickel and iron alloy	Cu = 10 % Ni = 25 % Fe = 65 %	1.400	Entire	2.800	Misplaced
17.	Magnalium	Cu = 1.76 % Ni = 1.16 % Mg = 1.60 % traces of Sb Fe, AL = balance	0.5980	8.380	1.8610	
18.	Ferro-boron	B = 20 - 25 % Fe = 80 - 75 %	0.0727	Entire	2.180	
19.	Silver aluminium alloy		12.70	3.90	2.42	Less rich in Ag. not homogeneous
20.	Silver aluminium alloy		9.45	5.94	2.48	Poor in Ag. not homogeneous
21.	Cobalt		18.30	91.50	2.50	
22.	Toncan metal		0.6000	Entire	3.2508	

No.	Names of alloys	Composition	Loss in weight in grams per sq. in. of surface in 4 N			Remarks
			HCl	HNO ₃	H ₂ SO ₄	
23	Giulinium		12.800	5.325	3.520	
24	American ingot iron	S = .018 % P = .005 % C = .012 % Mn = .010 % Si = .005 % Cu = .030 % O = .024 % N = .003 % H = .008 % Fe = balance	0.2800	Entire	2.0000	Mis-placed
25.	Aluminum, tin and nickel alloy	AL = 90 % Sn = 5 % Ni = 5 %	0.8820	2.5810	3.7840	
26	Alloy No. 2	Fe = 37 % Cr = 60 % Mo = 3 %	3.2600	0.5900	4.6800	
27	Vanadium and aluminum alloy		6.872	10.00	4.715	
28	Alloy No. 1	Fe = 37 % Cr = 60 % Mo = 2 % W = 1 %	4.02	0.185	4.77	
29	Manganese tin	Mn = 50 % Sn = 50 %	4.06	134.00	24.47	
30	Electro-lytic iron		1.83	65.92	36.00	
31	Openhearth steel	C = .19 % Mn = .42 % P = .17 % S = .0	1.42	62.23	41.90	
32	Electrolytic iron melted		0.880	Entire	Entire	
33	Ferro-chrome	Cr = 75 % Fe = 25 %	No loss	0.0161	Entire	
34	Chrome manganese	Cr = 30 % Mn = 70 %	7.86	0.39	Entire	

No.	Names of alloys	Composition	Loss in weight in grams per sq. in of the surface in 4 N			Remarks
			HCl	HNO ₃	H ₂ SO ₄	
35	Manganese-Titanium alloy	Ti = 35 % Mn = 65 %	2.56	9.16	Entire	
36	Ferro-titanium	Ti = 25 % Fe = 75 %	3.10	2.80	Entire	

Sources of Alloys.

Alloys Nos. 1,2 and 3 - Brass foundry of the Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.

Nos. 6 and 10 - The William Cramp and Sons, Ship and Engine Building Co., Beach and Ball Streets, Philadelphia, Pa.

Nos. 7,11,18,29,33,
34,35 and 36 - The Goldschmidt Thermit Co., West Street, New York City, N. Y.

Nos. 15, 19 and 20 - North American Selling Co., 120 Liberty Street, New York City, N. Y.

No. 16 - Mr. G. H. Clamer, Philadelphia, Pa.

No. 22 - Stark Rolling Mills Co., Canton, Ohio.

No. 5 - Aluminium Co., of America, New Kensington, Pa.

No. 4 - The Roessler and Hasslacher Co., 100 William's Street, New York, N. Y.

No. 12 - Aluminium Co of America, New Kensington, Pa.

-19 A-

No. 8 - Biddle Hardware Co., Philadelphia, Pa.

No. 13 - Hoskin's Manufacturing Co., Detroit,
Michigan.

No. 14 - Hermann Boker & Co., New York, N. Y.

No. 21 - E. H. Sargent & Co., Chicago.

No. 23 - Moline Automobile Co., Moline, Ill.

No. 27 - Vanadium Sales Co., of America, Pittsburgh, Pa.

No. 24 - The American Rolling Mill Co.,
Middletown, Ohio.

No. 26 and 28 - Prepared in this laboratory.

No. 30 and 32 - Made in the Department of Electrical
Engineering of this University.

No. 31 and 9 - T. and A.M. Laboratory of the
University.

DISCUSSION.

16 From the preceding table of results, it is evident that the presence of a certain metal or metals in an alloy has a marked influence on the acid-resisting properties. By comparing the alloys Nos. 31, 9, 11, 18, 33 and 36, it is found that the same metal, iron, being alloyed with different metals, gives entirely different properties. Steel, No. 31, loses a large part of its weight in sulphuric acid, the presence of titanium or chromium makes it still worse, and the presence of boron, molybdenum and copper makes it considerably resistant towards sulphuric acid. Considering nitric acid, it will be seen that the presence of titanium, chromium and copper is preferable to that of molybdenum and boron. Comparing alloy No. 10 with alloys Nos. 1, 2 and 3, it is seen that by replacing silicon of No. 10 by lead, the alloys Nos. 1, 2 and 3 have been made more resistant to both nitric and sulphuric acids. Again by alloying chromium with nickel, the alloy obtains greater power of resisting the action of sulphuric and nitric acids than nickel itself.

The proportions of the different components used in making alloys have a striking influence in giving the acid-resisting properties. For example, though alloys Nos. 16 and 8 have the same components, they differ greatly in their properties. Comparing alloys Nos. 34, 33, 13 and 7, it will be found that chromium, when alloyed with manganese or iron, resists the action of nitric acid very satisfactorily,

but dissolves entirely in sulphuric, the same metal when alloyed with copper dissolves entirely in nitric acid, but greatly resists the action of sulphuric. When chromium is alloyed with nickel, the product resists all acids fairly well. In the same way, titanium and iron, No. 36, resists the action of nitric acid better than titanium and manganese No. 35. Both however, dissolve entirely in sulphuric acid. Manganese and chromium, No. 34, resists the action of nitric acid considerably more than manganese and tin, No. 29, or manganese and titanium, No. 35; but in sulphuric all three are very easily soluble.

The hardness of alloys seems to play an important part in giving them high power of resistance towards corrosion. Samples Nos. 1, 2, 3, 6, 9, 10 and duriron are alloys which are very hard and all of them do withstand the action of acids very well. Duriron which is the hardest of all the alloys tested in this work, has the highest power to resist corrosion. But the harder the alloys, the more brittle they become and hence are less workable. Duriron is a striking example of this type of alloys.

The samples of silver aluminum alloys, Nos. 15, 19 and 20, were obtained from the North American Selling Co., of New York. The sizes of these samples as sent by the Co. were different; sample No. 15 being smallest, sample No. 19, being larger and sample No. 20 the largest. From these different sizes it was thought, that the smallest

must be most valuable and hence richest in silver and poorest in aluminum, that the next larger must contain less silver and more aluminum than the first and that the largest must have the least silver and most aluminum. But the results of corrosion tests on these samples were not in agreement with the results that were expected. For it is known that silver is almost insoluble and aluminum most soluble in hydrochloric acid. In the same way, aluminum is almost insoluble and silver most soluble in nitric acid. Hence the loss in hydrochloric acid per square inch of surface of sample No. 15, would be expected to be the least and the loss of alloy No. 19, would be less than that of No. 20 in the same acid. It is seen that the results actually obtained are quite different from those that were expected. Similarly the loss in nitric acid per square inch of surface of the alloy No. 15, should be the greatest, and the loss of alloy No. 19, should be more than that of No. 20 in the same acid. But this is also not the case. ¹⁷On looking up the literature, it was found that the silver aluminum alloys containing less than 10% of silver are not homogeneous. Hence it was thought that the results of analysis might throw some light on the true composition and nature of these alloys, and with this object in view the analyses were made.

The samples were dissolved in aqua regia and the solution carefully evaporated to dryness. The residue thus obtained was treated with water, whereupon it dissolved excepting the silver chloride. It is likely that some al-

uminum hydroxide will also be formed by hydrolysis and precipitate out with the silver chloride. In order to prevent this, a few drops of conc. hydrochloric acid were added to the residue, and then diluted with water. The solution was then filtered, the residue thoroughly washed with water slightly acidified with nitric acid, and then dried and weighed as silver chloride. This gives the percentages of silver in the alloys. Duplicate analyses were run, but no good checks were obtained. However, since the results of analyses showed that the maximum silver content in these alloys was only 4%, it was concluded that they are not homogeneous as is indicated in the literature.

Duriron is of particular interest to the chemical and metallurgical engineers on account of its remarkable resistivity towards chemical action. According to the manufacturers, it is an alloy containing from 12 to 15 per cent of silicon, the other ingredients being kept secret.¹⁸ It is stated in the advertisement, that when immersed in cold 25% sulphuric acid, it showed no loss in one year. In cold 25% nitric acid, it showed a loss of 0.015 per cent in one year. They further state that the resistivity of duriron to chemical actions decreases slightly with higher temperature. At the present time, some very interesting castings for chemical and general industrial work are being made by the duriron company of New York. These peculiar properties and its striking behavior towards the action of corroding agencies were of sufficient interest to warrant an analysis being made.

Not being soluble in the strongest acids and alkalies

or even by fusion with sodium peroxide, etc., the sample of duriron was finely powdered and treated with hydrofluoric acid which dissolved it but very slowly. The residue obtained after treatment with hydrofluoric acid was dissolved in hydrochloric acid and the solution analysed qualitatively. The results of the qualitative analysis showed the presence of iron only. This method, however, is unsuitable for quantitative analysis, because of the fact that silicon forms a compound that is completely or at least partially volatilized. Hence the following method was used to get the sample in solution. Using the sample as anode and platinum foil as cathode a current was passed through a hydrochloric acid solution as the electrolyte. With the passage of the current, the anode partly goes into solution and partly begins to scale off, the scales falling down to the bottom of the beaker. By weighing the anode before and after this treatment, the difference gives the accurate weight of the sample in hydrochloric acid either in the form of scales or in solution. The solution is then evaporated to dryness over steam bath and the residue treated with conc. hydrochloric acid. On heating for a short time the residue dissolves in the acid, leaving silica containing traces of iron and carbon. This solution was analysed qualitatively and iron was again the only metal found. Another sample was similarly treated, the solution obtained was filtered, and the residue thoroughly washed. The filtrate was made up to 500 cc. and then analysed for iron according to the potassium permanganate



Duriron
Unetched

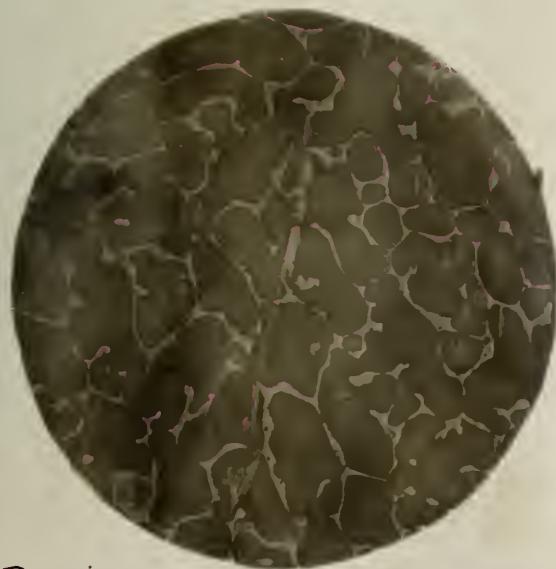
$\times 60$

Manuel



Duriron
Etched in HCl.

$\times 60$



Duriron
Etched in HCl.

$\times 350$

Duriron
Etched in HCl

$\times 350$

Manuel



method described by Treadwell and Hall¹⁹. The residue was analysed for silicon in the usual way²⁰. The following are the results obtained in the analysis.

First run	Second run
Fe = 86.02 %	Fe = 85.50 %
Si = 13.98 %	Si = 14.32 %
100.00	99.82

The photo-micrographs of duriron which will be found on the opposite page were made by Mr. W. A. Manuel of this Department.

²¹An alloy of ferro-chrome containing 2 - 5 % of molybdenum is advertised as being insoluble in aqua regia. Being unable to secure samples of this, it was thought worth while to make this alloy to study its properties. It has been shown that chromium when alloyed with iron imparts to the alloy high acid resisting properties. The presence of molybdenum in the alloy adds still more to its properties. Since chromium, molybdenum and tungsten fall in the same group of the periodic system, it was thought that the presence of tungsten, would give the alloy still higher power of resisting corrosion. With this object in view two alloys, Nos. 26 and 28, were made by the thermit process. From the amounts of oxides used, the alloy No. 28 should contain 37% of iron, 60% of chromium and 3% of molybdenum and No. 26 should contain 37% of iron, 60% of chromium, 2% of molybdenum and 1% of tungsten.

Neither of them, however, withstood the action of aqua regia, nor could they show even as good acid resisting properties as some of the other alloys.

SUMMARY

1. The relative resistance to hydrochloric acid, nitric acid and sulphuric acid has been determined for thirty-six metals and alloys.

2. Three silver-aluminium alloys were analysed to get the relation between the composition and the acid-resisting properties.

3. Duriron, an alloy that has not been patented, was found to contain only iron and silicon.

4. The thermit process was used in the preparation of some unavailable alloys advertised as acid-resisting.

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